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Centre

Effects of climate change in developing countries

November 2006

Summary

Future climate change will affect water supplies and food production. There will also be a wide range of other impacts, such as coastal flooding, increased heat related mortality, and loss of important ecosystems. In this report we present several new results:

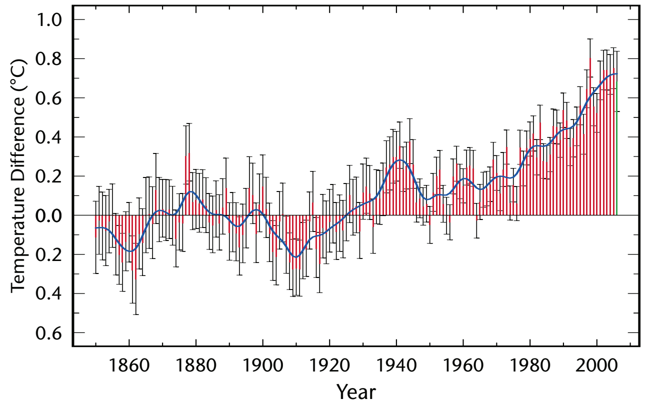
- observations of global temperature show that the recent warm period has continued. 2005 was the second warmest year on record.
- observations show that the fraction of the planet's land surface in drought has risen sharply since the start of the 1980s. Comparison with computer model simulations suggests this is likely to be due to human induced climate change.
- we project that by 2100, if significant mitigation does not take place, around half of the planet's land surface will be liable to drought. Some less developed countries are likely to be severely affected. Africa, South America and parts of South East Asia are likely to see worsening conditions.
- an important outcome of Met Office Hadley Centre work is the transfer of climate modelling skills to the developing world. We have provided a regional version of our climate model, and training on how to use it to produce climate scenarios, to researchers in more than 60 countries. Case studies from users in three regions (Southern Africa, the Indian sub continent, and China) are presented in this report.

Taken together the results presented here show further evidence of climate change, and project even larger changes in the future. More of the world is likely to be in drought. While increases in carbon dioxide concentration can actually enhance the productivity of plants, climate change will offset much of this enhanced growth. Increased incidence of fire may be made worse by more widespread drought, causing further damage to vegetation and increasing carbon emissions. While there may be some local "winners" who experience enhanced food production in coming decades, this is unlikely to continue with further climate change and must be viewed in the context of the many other negative impacts of climate change affecting these and other regions.

Recent climate change

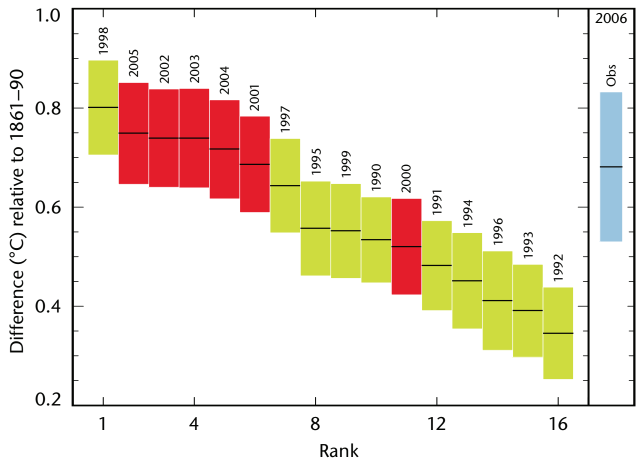
The global average surface temperature in 2005 was about 0.75 °C warmer than the average for the end of the 19th century, making it the second warmest year on record. The temperatures for each year relative to the end of the 19th century are shown in red in the Figure below. The part year result for 2006 between January and July is shown in green. The grey bars show our estimate of uncertainty in the results for each year, which is mostly due to the sparsity of measurements in some regions. Increasing the certainty will require further improvements to the measurement networks.

Global average surface temperatures and their uncertainty estimates with respect to the end of the 19th century.



The two periods of most rapid warming were during the 1930s and since around 1970. The top 16 annual average temperatures in the instrument record (since 1860) are listed in order in the Figure below. It is notable that the top 10 have all occurred since 1990.

Warmest years on record: black line is the best estimate and the bar represents the range of probable values. Observed temperature difference for 2006 using data between January and July is shown in blue.

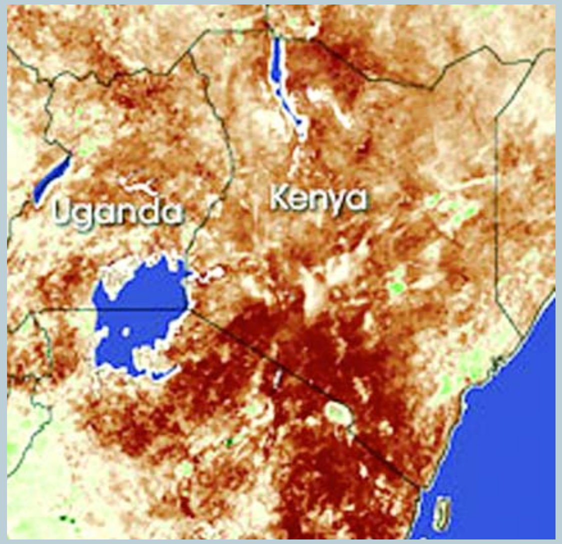


Both short and long term warming varies from location to location. So far, in 2006 the global average anomaly is less than 1 °C. However, during the same period some areas of the northern hemisphere, particularly the USA, Canada and much of Asia have been between 1 and 3 °C warmer than the average for the end of the 19th century.

Despite the record temperatures experienced in parts of the northern hemisphere between June and the early part of August in 2006, the beginning of the year was cool. Consequently, as a global average this year is unlikely to be the warmest on record but is still likely to be well within the top 10.

Impact of drought in Kenya

Satellite image of Kenya for February 2006, processed to show changes in vegetation cover (www.modis.gsfc.nasa.gov). The brown areas indicate significant reductions in vegetation cover.



A severe drought caused by low rainfall struck northern and eastern Kenya in 2006, peaking in February. Nearly 10% of the population faced starvation. The brown areas in the Figure above show where the vegetation cover was greatly reduced.

Despite some rainfall in May, pasture is still scarce, and the crisis continues. Many other people in the horn of Africa have also been affected by the drought.

Global drought

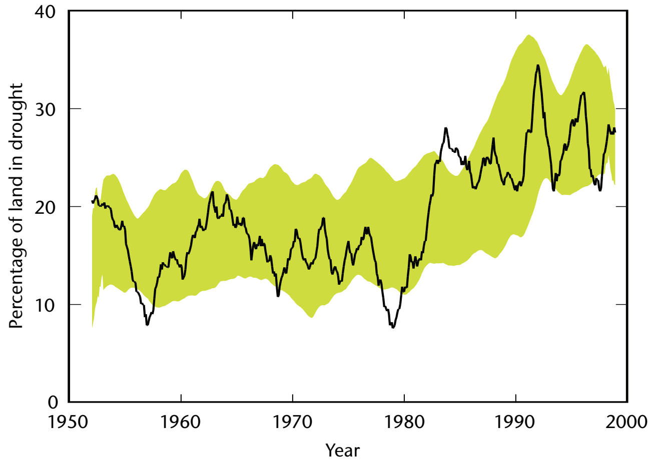
Drought can lead to failed harvests and famine. Those likely to be hardest hit are in developing countries where populations rely heavily on rain fed agriculture and food infrastructures are less resilient.

Changes in the recent past

Drought can occur because there is too little rainfall or too much evaporation (for example, if temperature increases). The Palmer Drought Severity Index (PDSI) captures these factors and is commonly used as a measure. This index has been adapted to identify the percentage of land suffering from drought[1]. The observations below indicate that the extent of drought has risen substantially since 1980.

When the Met Office Hadley Centre global climate model includes the combined effect of natural forcings (volcanoes and solar radiation changes) and observed increases in greenhouse gases, it is able to reproduce this increase reasonably well. When only natural forcings are included it does not. This result suggests the observed increases in drought are likely to have a human cause.

Observed (black line) and simulated (green area) change in historical amount of land in drought. The width of the shading represents the uncertainty in the model results.

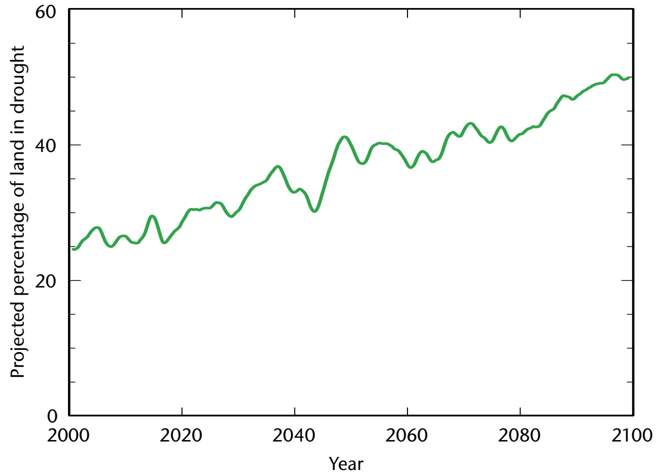


Future projections

The Met Office Hadley Centre global climate model has been used to project the percentage of the land area that will experience drought during the 21st century assuming SRES A2 emissions[2].

Even though (globally) total rainfall will increase as the climate warms, the proportion of land in drought is projected to rise throughout the 21st century because some areas are likely to experience less rainfall, and evaporation will be enhanced in a warmer climate. Without significant mitigation of emissions, by 2100 the area affected by drought is projected to double in extent from 25% to 50%. The number of drought events are projected to increase only slightly but they will last much longer.

Projected percentage of land in drought between 2000 and 2100 under the SRES A2 scenario.



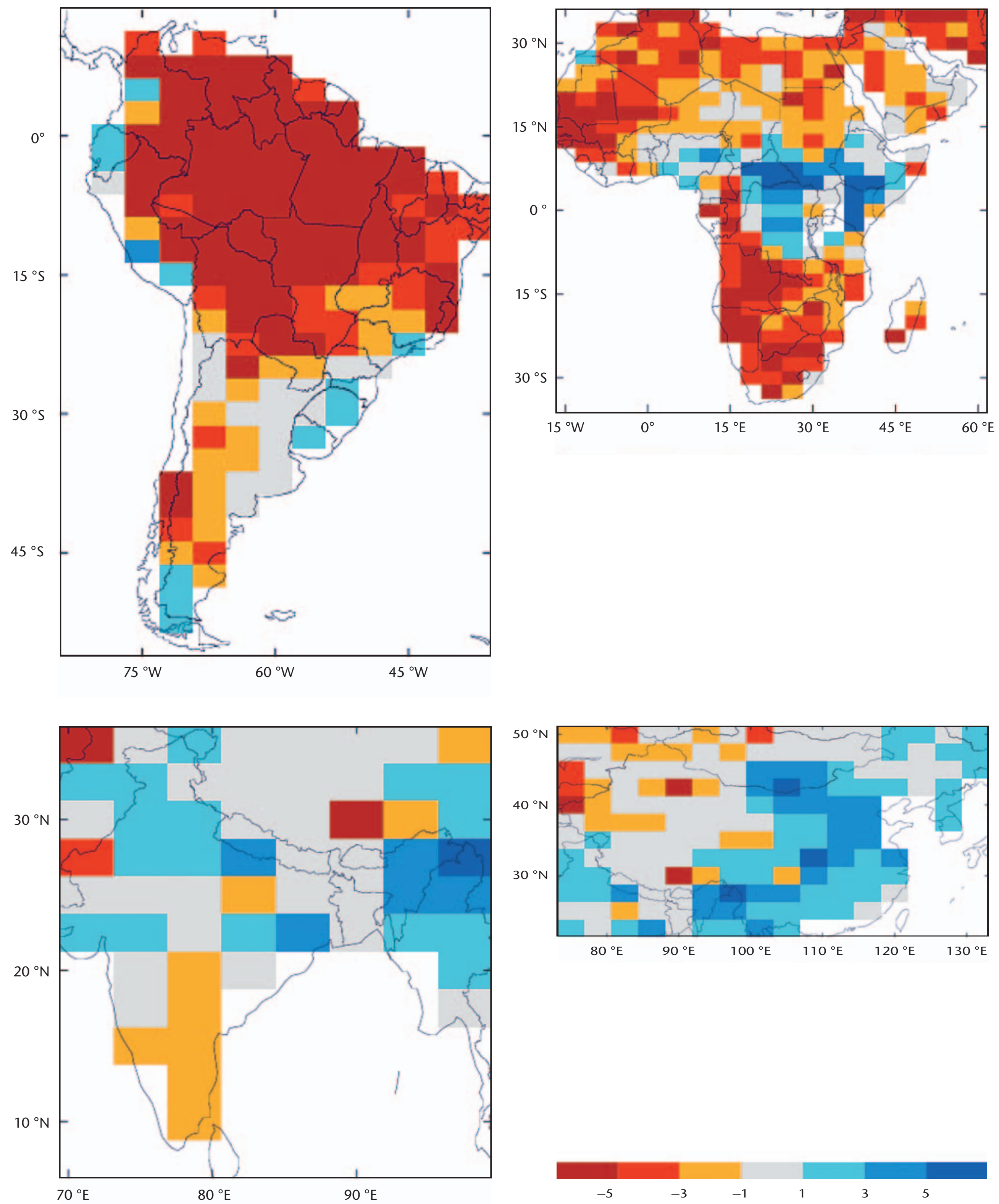
The Figures on the facing page show projected changes in the patterns of PDSI between the present day and a SRES A2 climate. The model does not reproduce observed changes in drought for some regions and therefore these regional changes are uncertain. However, they provide an indication of potential future changes.

These projections indicate that much of Africa and South America experience more droughts. In 2005, a severe drought occurred in the Amazon region. Dry spells are not unusual in the Amazon, but normally occur in El Niño years. However, 2005 was not an El Niño year. If droughts of this severity occur more frequently, the forest will decline with severe local impacts. It may also affect global climate by altering the strength of the natural carbon sink.

The projections for India and China are more mixed and uncertain. Projections from other climate models also give a mixture of increases and decreases in drought in India and China, but the patterns are different.

[1] A drought threshold has been identified for each location. The threshold is defined so that 20% of all months from 1950 to 2000 have PDSI values below it. The percentage of land below these thresholds has then been identified. Note that the average over this period is 20% by definition.
[2] In the SRES A2 climate projection the carbon dioxide emissions increase from 8 GtC / yr in 2000 to 29 GtC / yr in 2100. The global warming predicted by the Met Office Hadley Centre model between the present day and the 21st century is 3.8 °C

Mean change in PDSI over South America, Africa, India and China for an SRES A2 climate, between the present day and 2090s. Negative values (red and orange) indicate areas projected to become more prone to droughts under this scenario, whereas regions with positive values (blue) are projected to become wetter and less prone to droughts.



PRECIS

Providing REgional Climates for Impacts Studies

To simulate climate on local scales, the Met Office Hadley Centre has developed a regional climate modelling system, PRECIS (Providing REgional Climates for Impacts Studies). Regional climate models employ higher resolution than global models and add valuable detail to regional climate scenarios which are required when assessing a region's vulnerability to climate change.

PRECIS can be run on a personal computer and applied easily to any area of the globe. It is available free of charge to developing countries (www.precis.org.uk) so that they can produce high resolution climate change scenarios at national centres of expertise.

PRECIS user network and data centres

PRECIS has over 190 users from more than 60 countries worldwide (locations are shown in the Figure below). Users obtain PRECIS via participation in regional workshops. PRECIS is usually applied collaboratively over a region with southern and central Africa, South America, the Caribbean and Central America, the Middle East and most of Asia (as well as Europe and North America) being covered. In many regions PRECIS data are readily available from participating institutes. For example, an internet-based data acquisition and analysis system has been developed by the Cuban Meteorological Institute (INSMET). This system provides both climate data and visualisation facilities from PRECIS experiments run over the Caribbean/Central American region.

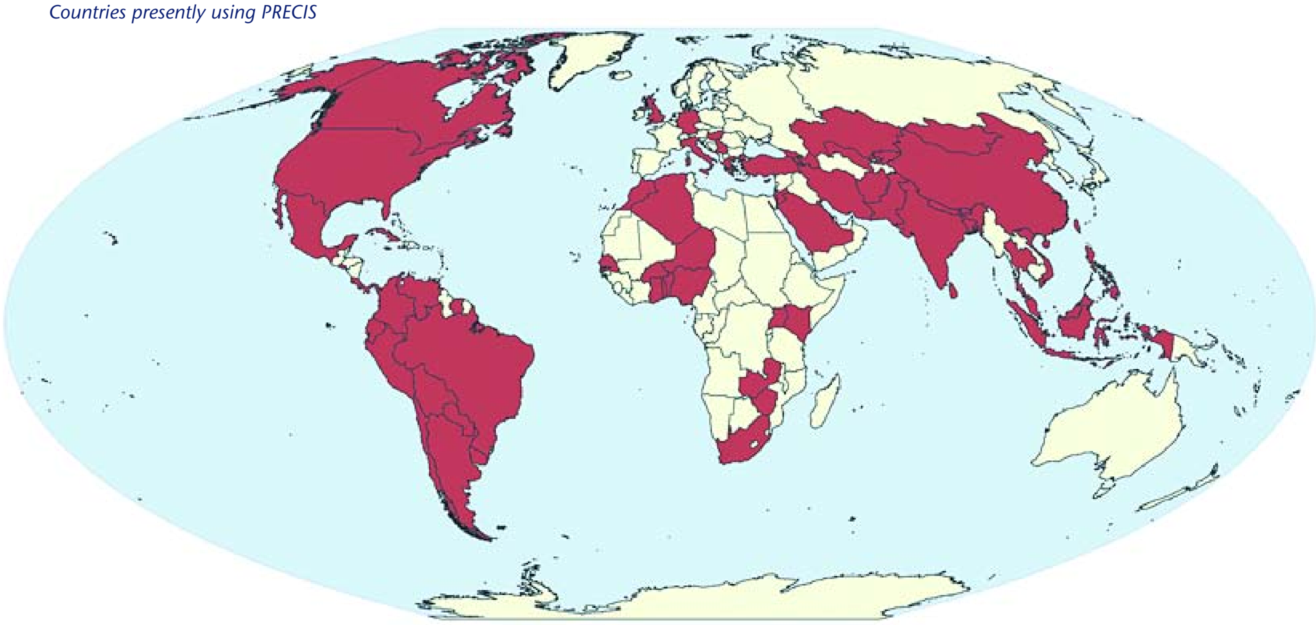
PRECIS has been used extensively for sub-Saharan Africa. Actively engaging with scientists and stakeholders within the region has helped develop the human resource and institutional networks for climate and related research.

Workshops in South Africa have provided training for climate modellers across Africa. The PRECIS infrastructure has been set up to provide high resolution data for climate change research. This infrastructure will be provided for Madagascar and other neighbouring countries.

A joint workshop on PRECIS and ecological modelling in Ghana provided an environment for researchers from many different disciplines to interact.
Over 40 participants from the West African region attended this workshop, with representatives from the United Arab Emirates, Morocco and Uganda also present.

Future activities will include building further capacity over Eastern, Central and Northern Africa, including the island states in Africa. We also envisage providing PRECIS to the island states in the Pacific and working to establish a network of PRECIS users and modelling infrastructure to focus on accurate representation of climatic processes over the region. This activity would benefit from the experience derived from the Caribbean and Central American PRECIS activities.

Countries presently using PRECIS

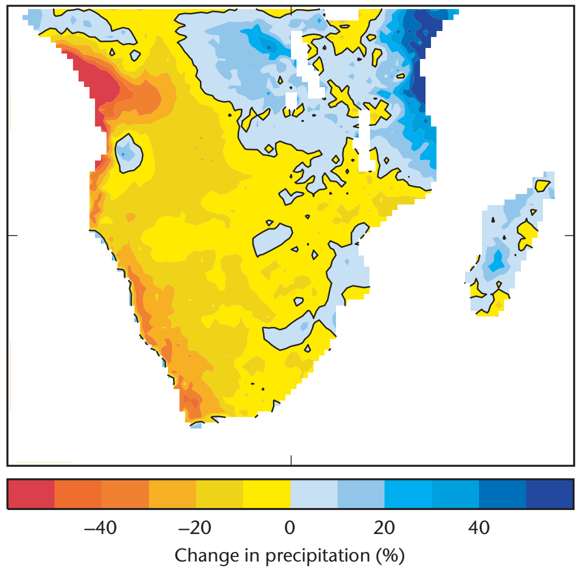


Africa

Africa is the world's second largest continent and accounts for 12% of the world's population. Substantial parts of Africa depend on scarce water supplies for drinking and irrigation of crops. Indeed, the majority of Africa's population depend on rain fed agriculture for their livelihoods (over 70% in sub-Saharan Africa).

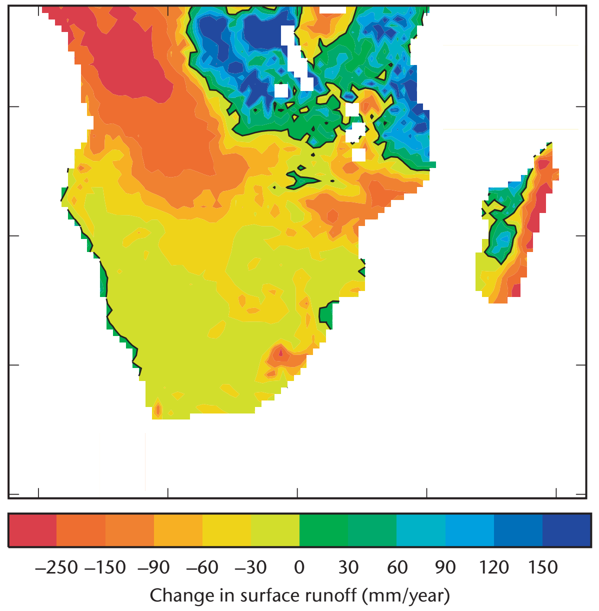
PRECIS has been used to assess the impact of climate change on a local scale. Results from studies of sub-Saharan Africa (roughly 10°E to 50°E; 0° to 40°S) are highlighted here. For the SRES A2 emissions scenario, PRECIS projects an average surface warming over the subcontinent of 3.8 °C in summer and 4.1 °C in winter by the 2080s. A reduction in rainfall over much of the western and subtropical areas is projected. Conversely, wetter conditions occur over eastern equatorial and tropical southern Africa during summer in these simulations. The results for precipitation are shown in the Figure below.

Percentage change in precipitation by 2080, as projected by PRECIS under the SRES A2 scenario.



Projections of future runoff (a measure of the amount of water flowing in rivers and in ground water) provide valuable information for water resource planning. The changes in annual average surface runoff between the recent climate and the 2080s were calculated from PRECIS climate projections and show large increases in the north east of the region, large decreases in the north west and smaller decreases to the south (top right Figure). In the north east of the region precipitation and runoff increase but PDSI indicates more drought (pages 2-3). This apparent difference may arise because of the strong dependence of PDSI on temperature and reflects increased evaporation in a warmer climate.

Change in surface runoff by 2080 from PRECIS under the SRES A2 scenario.

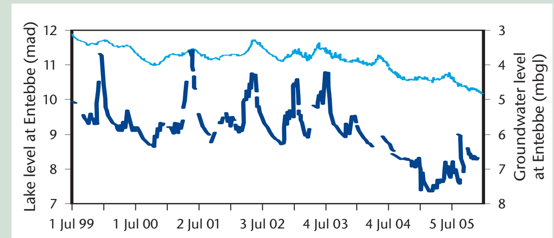


PRECIS-based projects on water resources in Africa

PRECIS is being applied to assess the impacts of climate change and variability on water resources in Uganda.

A rainfall-runoff model is being driven using results from PRECIS simulations. Output from this study will eventually be able to provide estimates of such quantities as the regionally important water-level fluctuations in Lake Victoria. The outcome of these studies will strengthen the decision support base of the region.

Recent observed changes in lake depth (mean area depth in metres, thin line) and groundwater (metres below ground level, thick line) at Entebbe, Uganda[3].



[3] C. P. K. Basalirwa and R Taylor. Assessing the impacts of climate change and variability on water resources in Uganda: developing an integrated approach at the sub-regional scale, START Project Report number 202 457 5859, February 2006.

PRECIS

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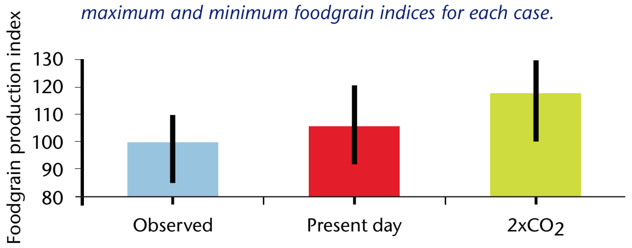
India

India is the second most populated country in the world with around 1.1 billion people. Around 60% are employed in agricultural activities. Between 75% and 90% of the country's rainfall occurs during the monsoon period (June to September), and sustains the Kharif season crops that are harvested during the autumn. This rainfall also provides moist soils and water for lakes and dams that in turn are used for irrigation during the later Rabi crop season.

The production of crops can be represented by a foodgrain production index. Calculations from observed and modelled monsoon conditions agree reasonably well (as shown in the Figure below). If future climate stabilises at 2xCO_2, monsoon rainfall is likely to increase, leading to increased food production. If the effects of increased CO_2 levels on crop growth were also included, it is likely that the projections of future production would be even larger. However, the use of this broad scale index conceals important local details.

Observed (blue) and simulated (red) foodgrain production indices for the present day. The global model projected foodgrain index for 2xCO_2 is also shown (in green). The vertical black lines illustrate the maximum and minimum foodgrain indices for each case.

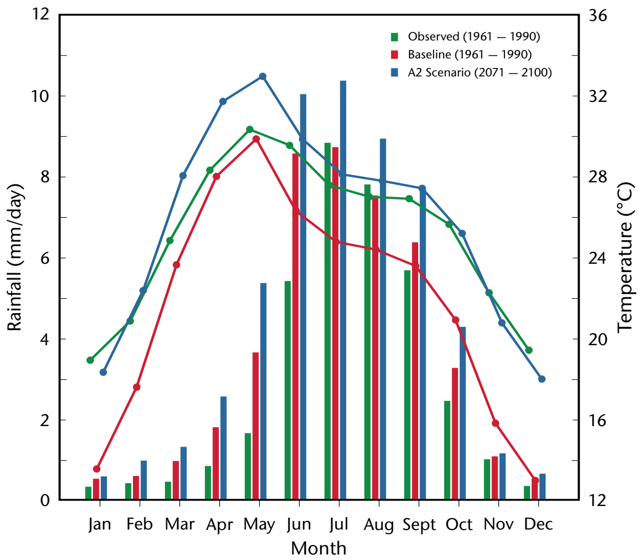


PRECIS has been used to add more local detail to the climate change projections. Simulations were made of the monthly temperature and rainfall over India for the periods 1961-1990, and 2071-2100 for an SRES A2 emissions scenario. Both quantities are projected to rise in the future, as shown in the Figure (top right).

A crop model, driven using climate data from PRECIS, was used to simulate the mean fraction of setting pods in groundnut. The fraction of setting pods projected for the 2080s assuming no adaptation, is shown in the Figure (right). Low fractions are associated with low crop yield and are the result of heat or water stress during the flowering period.

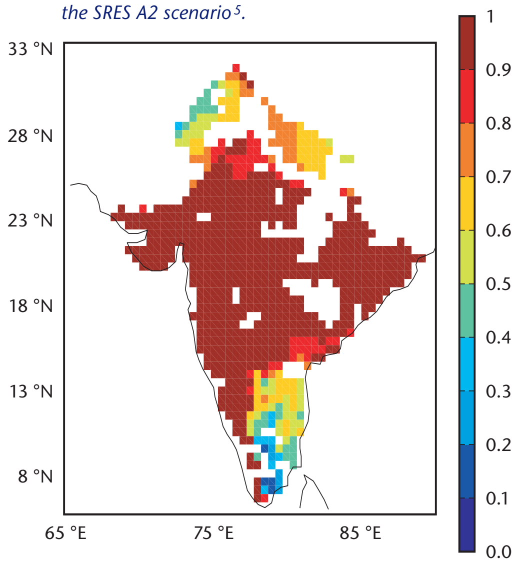
[4] K. Rupa Kumar*, A. K. Sahai, K. Krishna Kumar, S. K. Patwardhan, P. K. Mishra, J. V. Revadekar, K. Kamala and G. B. Pant. High-resolution climate change scenarios for India for the 21st century, Current Science, Vol. 90, No. 3, 10 February 2006.
[5] Challinor, A. J., T. R. Wheeler, T. M. Osborne and J. M. Slingo (2006). Assessing the vulnerability of crop productivity to climate change thresholds using an integrated crop-climate model. In: Avoiding Dangerous Climate Change. Schellnhuber, J., W. Cramer, N. Nakicenovic, G. Yohe and T. M. L. Wigley (Eds). Cambridge University Press. Pages 187-194.

PRECIS simulation of temperature and precipitation over India for the period 1961-1990 (red) and 2071-2100 (blue). Observations for 1961-1990 are shown in green. The bars represent rainfall, and the solid lines temperatures. These data are averages over the entire country[4].



This effect is seen in most annual crops, including wheat, rice and maize. In the present day (not shown) there is very little heat and water stress in northern India but significant stress in the far south leading to low setting of groundnuts. The heat and water stress is projected to stay roughly the same in most parts of India but to increase in the north. Consequently, the setting of groundnuts in the 2080s is projected to be similar to present day in most regions, but to be substantially reduced in the north.

Mean simulated fraction of setting pods in groundnut by the 2080s for the SRES A2 scenario[5].



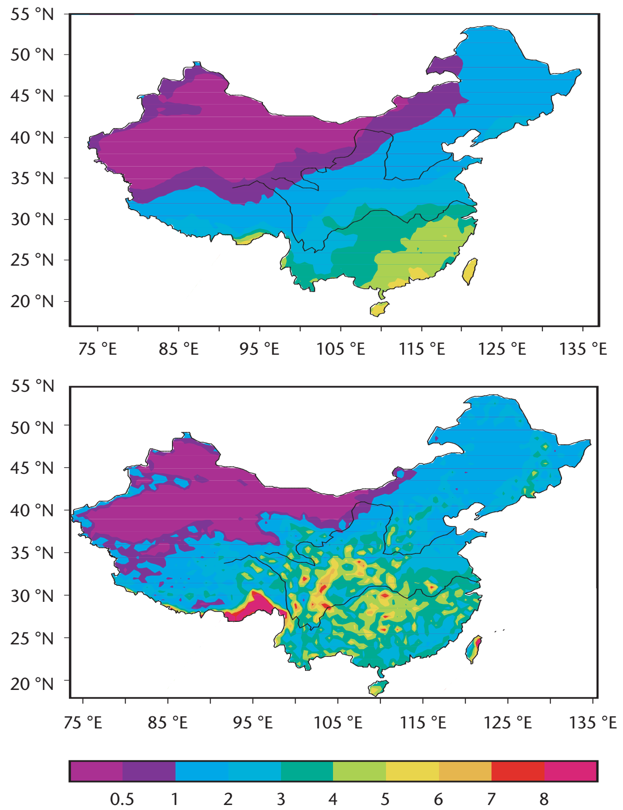
These results will help to inform adaptation strategies, to cope with climate change impacts on the region's agricultural systems.

China

The pattern of climate change is likely to vary considerably across the large Asian continent. Here we focus on China, the most populous country in the world.

PRECIS is able to accurately simulate regional temperature and precipitation patterns over China for the recent past as shown below for precipitation. Projections of China's future climate under the SRES A2 emissions scenario suggest a temperature rise of around 3.9 °C and a 13% increase in rainfall by 2080.

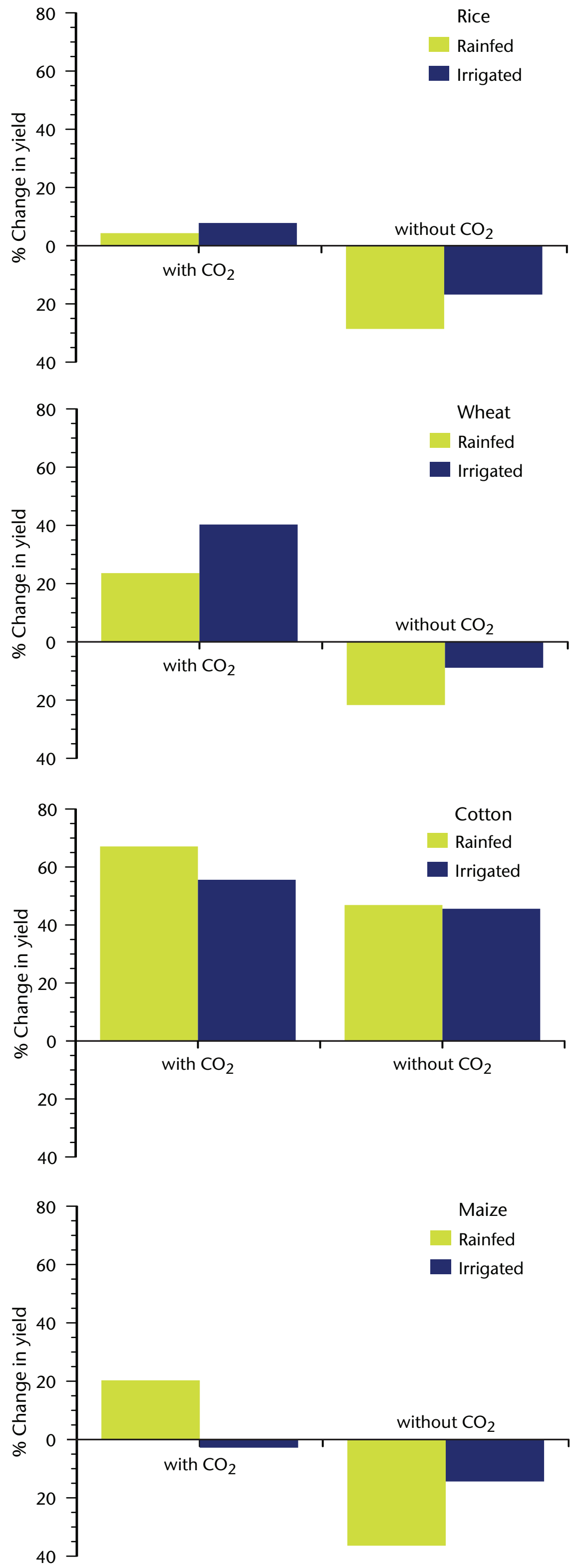
Average annual precipitation (mm/day): observations (top) and PRECIS simulation (bottom)[6].



The output from PRECIS has been used to project changes in yields of agricultural crops (rice, wheat, cotton and maize; see Figure opposite). For some crops, climate change reduces the crop yield. However, the direct effects of CO_2, which tend to enhance plant growth, more than counteract the damaging effects of climate change (compare the left hand and right hand pairs of bars in each of the Figures opposite).

As one might expect, in absolute terms irrigated crops are more productive than rain fed crops (not shown). When it comes to changes in production, irrigated and rain fed crops respond differently. Yields from irrigated rice and wheat increase more than rain fed crops. Conversely, yields from rain fed maize and cotton increase more than yields from irrigated varieties. Maize and cotton are currently water stressed and benefit more from the increased CO_2.

Projected changes (%) in yield of rice, wheat, cotton and maize by 2080[7].



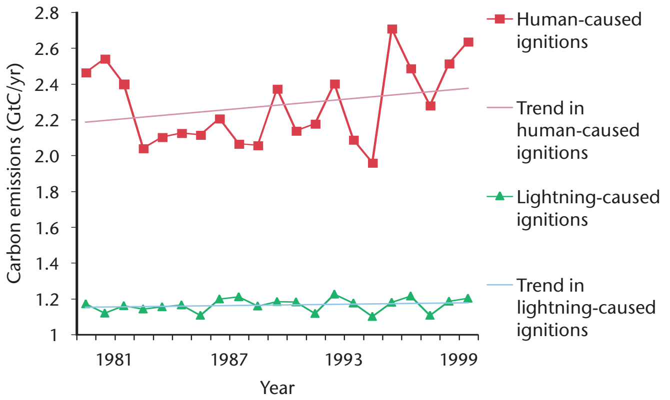
[6] X. Yinlong, Z. Yong, L. Yihua, L. Wantao, D. Wenjie, R. Jones, D. and S. Wilson Analyses on the climate change responses over China under SRES B2 scenario using PRECIS, PRECIS report.
[7] Based on data from L. Erda (2004): Investigating the impacts of climate change on Chinese agriculture: China-UK collaboration project, 2004.

Climate change and fire

The burning of vegetation in fires is an important element of the climate system. In the distant past fires were started largely by lightning, and very occasionally by volcanic eruptions. The frequency of the fires and their extent were regulated by climate conditions. Humans have long-changed natural patterns of wildfires through accidental or intentional ignition but also through fire suppression policies.

Recent ground-based and satellite observations, and simulations using a global fire model at the Hadley Centre, show carbon emissions from human-ignited fires have been gradually rising over the past two decades (Figure below). During the 1990s the carbon emissions from this source were around 2.3 GtC/yr, which is significant compared to global fossil fuel emissions in 2000 of around 6.5 GtC/yr.

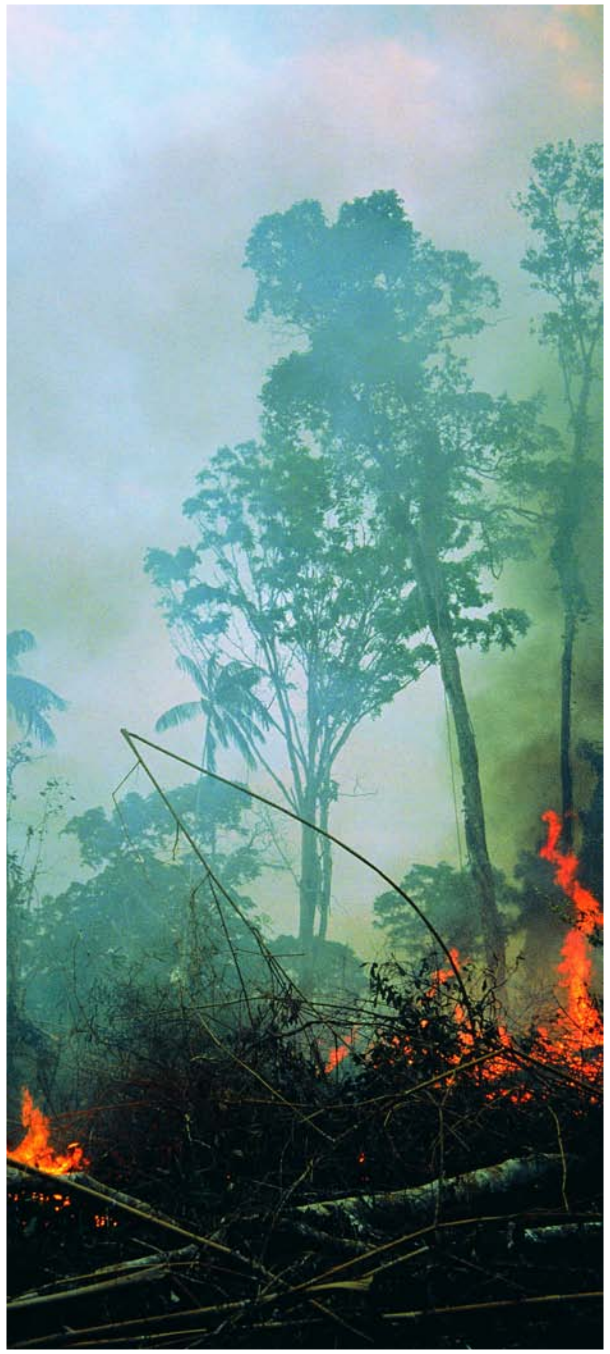
Simulated global carbon fire emissions from 1980 to 2001



Human and naturally ignited fires burn more readily and extensively when the vegetation and soil are dry. The strength of carbon emissions from both types of fire depend on climate conditions. This is evident in the large number of Indonesian fires and associated increase in carbon emissions during the 1997-1998 El Niño event.

In the future increased drought due to global warming (see page 2) could increase the incidence and extent of fire. Combining the impact of increased population density on human-ignited fires with the impact of climate change on the incidence and extent of fires, it is possible to estimate the increase in carbon emitted by fires by 2100. If all the past increases in fires were due to population increase then we would expect future carbon emissions to further increase by 0.5 GtC/yr by 2100 based on estimates of population growth. If some of the past change is due to temperature rise then the increase in future emissions will be even larger.

Understanding this source of emissions is especially important in the context of the large reductions in emissions that would be needed to stabilise global mean CO_2. In order to stabilise atmospheric CO_2 at 450 ppm total man made carbon emissions will eventually need to fall to around 1 GtC/yr[8].



[8] Based on WRE 450 emissions scenario: T.M.L. Wigley, R. Richels and J.A. Edmonds (1996), Economic and environmental choices in the stabilization of atmospheric CO_2 concentrations. Nature 379, 240-243.

Met Office Hadley Centre staff: 2006

The Hadley Centre for Climate Change was established within the Met Office in 1990, and currently employs over 120 scientists and support staff. The majority of the research work carried out within the Met Office Hadley Centre uses a world-leading global climate model that includes many different components of the climate system.

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Peili WU

This report also features work from scientists around the world who use the PRECIS modelling system. The Met Office provides training in the use of this model and the production of climate change simulations.

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